Sampling Design for Assessing Water Quality of the Red River of the North Basin, Minnesota, North Dakota, and South Dakota, 1993-1995

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Abstract

This map report describes the sampling design for a comprehensive regional assessment of water quality in the Red River of the North Basin, a study unit under the U.S. Geological Survey's National Water-Quality Assessment Program. The sampling design was developed to address questions about the presence, distribution, and loads of nutrients and pesticides associated with large agricultural regions in the basin and across the Nation. The design also begins to address major local and regional concerns about suspended sediment in surface water and naturally occurring salinity in ground water. Recognizing that the Red River of the North Basin study unit realistically could not be analyzed as a single homogeneous area, a hierarchical sampling stratification for assessing water quality was developed. Landscape features consisting of physiography, soils, land cover and land use, and cropping patterns provided the environmental framework for stratification of streams and surficial aquifers. The environmental framework characterizes the climate and hydrology and relates closely to an ecoregions framework. The environmental and ecoregions frameworks were considered in locating ecological sampling sites. For the subsurface framework, buried sand and gravel aquifers in study unit were subdivided into two general subregions of differing potential saline recharge from underlying bedrock aquifers.

Actual sampling sites for streams, aquatic biology, and ground water were described within the proposed sampling stratification. Practical considerations of previously established sampling sites, background information from previous hydrologic investigations, and site suitability for sampling protocols also were considered for final site selection.

Introduction

The mission of the U.S. Geological Survey (USGS) is to assess the quantity and quality of the earth resources of the Nation and to provide information that will assist resource managers and policymakers at Federal, state, and local levels in making sound decisions. Assessment of water-quality conditions and trends is an important part of this overall mission.

One of the greatest challenges faced by water-resources scientists is acquiring reliable information that will guide the use and protection of the Nation's water resources. That challenge is being addressed by Federal, state, interstate, and local water-resource agencies and by many academic institutions. These organizations are collecting water-quality data for a host of purposes that include: compliance with permits and water-supply standards; development of remediation plans for a specific contamination problem; operational decisions on industrial, wastewater, or water-supply facilities; and research on factors that affect water quality. An additional need for water-quality information is to provide a basis on which regional and national-level policy decisions can be based. Wise decisions must be based on sound information. As a society we need to know whether certain types of water-quality problems are isolated or ubiquitous, whether there are significant differences in conditions among regions, whether the conditions are changing over time, and why these conditions change from place to place and over time. The information can be used to help determine the efficacy of existing water-quality policies and to help analysts determine the need for, and likely consequences of, new policies.

To address these needs, the Congress appropriated funds in 1986 for the USGS to begin a pilot program in seven project areas to develop and refine the National Water-Quality Assessment (NAWQA) Program. In 1991, the USGS began full implementation of the program. The NAWQA Program builds upon an existing base of water-quality studies of the USGS, as well as those of other Federal, state, and local agencies. The objectives of the NAWQA Program are to:

- Describe current water-quality conditions for a large part of the Nation's freshwater streams, rivers, and aquifers.
- Describe how water quality is changing over time.
- Improve understanding of the primary natural and human factors that affect water-quality conditions.

This information will help support the development and evaluation of management, regulatory, and monitoring decisions by other Federal, state, and local agencies to protect, use, and enhance water resources.

The goals of the NAWQA Program are being achieved through investigations of 60 of the Nation's most important river basins and aquifer systems, which are referred to as study units. These study units are distributed throughout the Nation and cover a diversity of hydrogeologic settings. More than two-thirds of the Nation's freshwater use occurs within the 60 study units and more than two-thirds of the people served by public water-supply systems live within their boundaries.

National synthesis of data analysis, based on aggregation of comparable information obtained from the study units, is a major component of the program. This effort focuses on selected water-quality topics using nationally consistent information. Comparative studies will explain differences and similarities in observed water-quality conditions among study areas and will identify changes and trends in their causes.

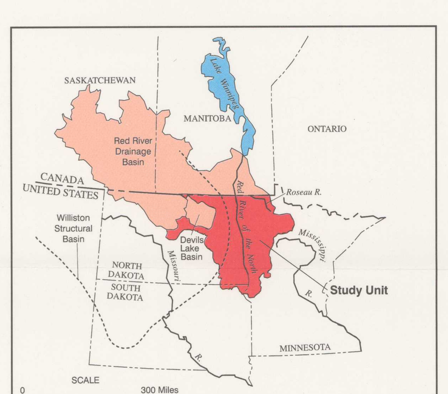


Figure 1.--Location of the Red River of the North Basin study unit.

The Red River of the North (hereinafter Red River) Basin was selected as a study unit under the NAWQA Program because the basin represents an important hydrologic region where water is a valuable resource for the region's economy, the quality of the Red River is of international concern, the basin represents an important agricultural area, and the northern location is important for a complete understanding of the Nation's water quality. The Red River is located near the geographic center of the North American continent and the river flows north. The Red River Basin study unit (fig. 1) includes the surface drainage to the Red River and Roseau River within the United States. The Devil's Lake Basin is not part of the study unit.

Purpose and Scope

The purpose of this report is to briefly describe the environmental framework and sampling design for the Red River Basin study unit assessment of water quality during 1993-1995. Sampling design, which includes sites for stream-water quality, aquatic biology, and shallow ground-water quality, is described within the context of a framework of land features. The influence of bedrock aquifers also was considered to design sampling of buried aquifers in glacial sediments.

Acknowledgments

This report is an element of the comprehensive body of information developed as part of the NAWQA Program. The program depends heavily on the advice, cooperation, and information from many Federal, state, Provincial, interstate, Tribal, and local agencies and the public. The authors thank Bruce Seelig of the Red River NAWQA liaison committee, who provided valuable input. The authors recognize the following people of the U.S. Geological Survey: G.J. Wiche for assistance with analyzing surface-water statistics and technical reviews; T.K. Cowdery for assistance with ground-water data; R. Borgstede, R.A. Miller, and J.A. Tapper for their assistance in the final preparation of the plates.

Environmental Framework

A framework of environmental factors was developed for the Red River Basin study unit to compare water quality within the area. For each study unit, such as the Red River Basin study unit, large amounts of water-quality and related data were collected in a few selected areas with the intention of making inferences about water quality in other areas within the study unit that were not sampled. Many natural and human factors, such as geology, climate, water use, and land use, affect the quality of water. A review of those factors clearly indicates that the Red River Basin study unit cannot be realistically analyzed as a single homogeneous area for assessing water quality (Stoner and others, 1993). Many of these factors are common to other hydrologic systems, but affect the water quality to varying degrees. Factors, such as physiography, geology, soils, and land use, provide a unifying framework for making comparative assessments of water quality in different parts of the Nation (Gilliom and others, 1995).

Land features are characteristics of the land surface and subsurface, including topography, drainage, geology, land cover and land use, and soil. Topography, drainage, and surficial geology are evaluated together as physiographic features. Physiography, soil, and land cover and land use were used to develop the framework because they describe most of the variability between different regions of the study unit and because other important factors, such as climate and hydrology, are correlated with these land features.

The three primary features of the environmental framework (figs. 2-4) are closely interrelated. For example, the surficial geology, climate, and hydrology are primary factors that relate to major areas of physiography and to soils of the Red River Basin study unit. Soils, in turn, are closely related to the land cover and land use; and specifically related to the major cropping patterns and intensity on cropland.

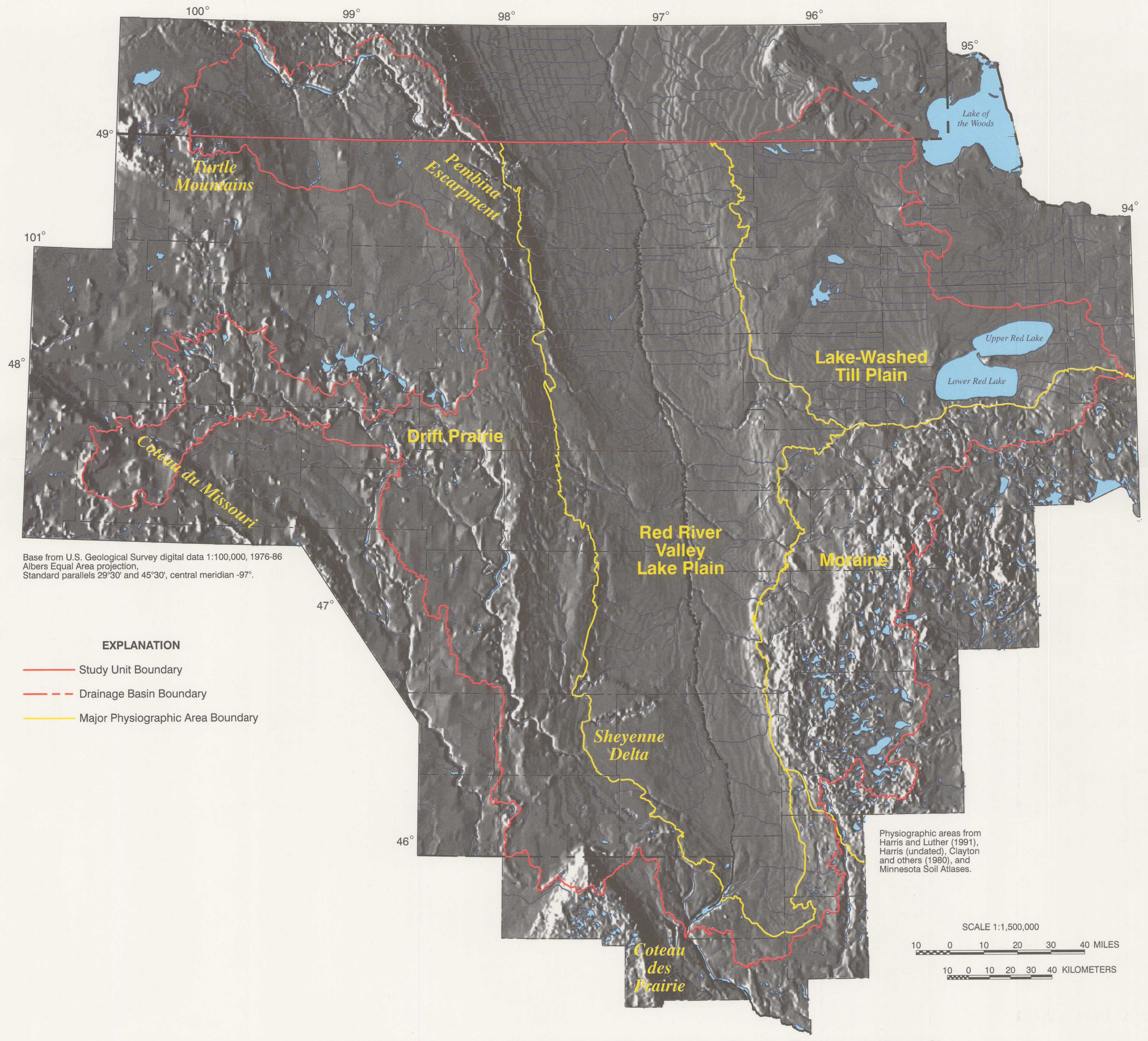


Figure 2. Physiographic areas in the Red River of the North Basin study unit.

Physiography

The relatively small topographic relief of about 1,600 ft (feet) and gently rolling hills and plains were largely caused by the actions of glaciation and geologically recent erosion. Glacial Lake Agassiz left clay-rich sediments in a flat lake plain along the axis of the Red River (the Red River Valley Lake Plain) and in the Lake-Washed Till Plain in the northeastern part of the basin (fig. 2). Ice-sheet advances and recessions left upland moraines and other glacial drift that extend east and west of the lake plain. Glaciers and glacial meltwater also left elongated ridges of beach sands and gravels and flat sandy outwash plains.

Land surface altitudes in the study unit range from 2,350 ft above mean sea level in the northwestern part to about 750 ft where the Red River crosses the U.S.-Canadian border. The altitude of the Lake-Washed Till Plain ranges from about 1,200 ft in the eastern part to about 1,000 ft where it meets the Red River Valley Lake Plain. The Moraine is dominated by about 200-ft hills above lakes and valleys that range in altitude from 1,400 ft in the east to 1,100 ft near the lake plain. Most of the Drift Prairie is an area of low rolling hills ranging in altitude from 1,400 to 1,500 ft. The western edge of the Drift Prairie rises from about 1,600 ft to about 2,100 ft at the margin of the Coteau du Missouri. The eastern edge of the Drift Prairie ends abruptly at the Pembina Escarpment and more gradually elsewhere. The Turtle Mountains are hills that rise about 550 ft above the surrounding plain that has an altitude of about 1,800 ft.

The Red River Valley Lake Plain slopes very gently, about 1 foot per mile (ft/mi) along the axis of the Red River and almost a uniform 5 ft/mi perpendicular to the axis of the Red River. The lake plain in the northeast grades into the Lake-Washed Till Plain, which is characterized by extensive wetland areas, where the surface slope is almost flat with a few small ridges. In the southeastern part of the lake plain, the land surface rises almost uniformly into the upland hills of the glacial Moraine area where many lakes and wetlands are found among 200-foot hills. The gentle slopes of the Red River Valley Lake Plain merge with the low rolling hills and prairie potholes of the Drift Prairie, but ends abruptly at the Pembina Escarpment. Prairie potholes are small ponds surrounded by marshy areas that occupy local depressions and collect rainfall and snowmelt. The Coteau du Missouri and Coteau des Prairie, within the Drift Prairie, have steep margins and have about 500 ft of local relief (fig. 2).

The river slopes vary considerably throughout the study unit, but most slopes are less than 10 ft/mi. Headwaters draining the Coteau des Prairie can have slopes exceeding 80 ft/mi. The Sheyenne and the Pembina Rivers drain extensive areas of the Drift Prairie. The average slopes of these rivers are about 1.2 and 4.0 ft/mi, respectively. The slope of larger rivers draining the Moraine area ranges from about 4 to 13 ft/mi. The slope of headwaters can be as large as 20 ft/mi. The slope of rivers draining the Lake-Washed Till Plain ranges from about 1 to 5 ft/mi. Slopes of small tributaries to the Red River that drain the Red River Valley Lake Plain range from 3 to 7 ft/mi. In the Red River Valley Lake Plain and the Lake-Washed Till Plain, natural drainage is augmented by drainage ditches and channelized rivers. The slope of the main channel of the Red River is 0.5 ft/mi. The natural drainage pattern, relatively steeper streams draining into lower slope, and slower moving streams in the Red River Valley Lake Plain can augment flooding from rainfall and snowmelt.

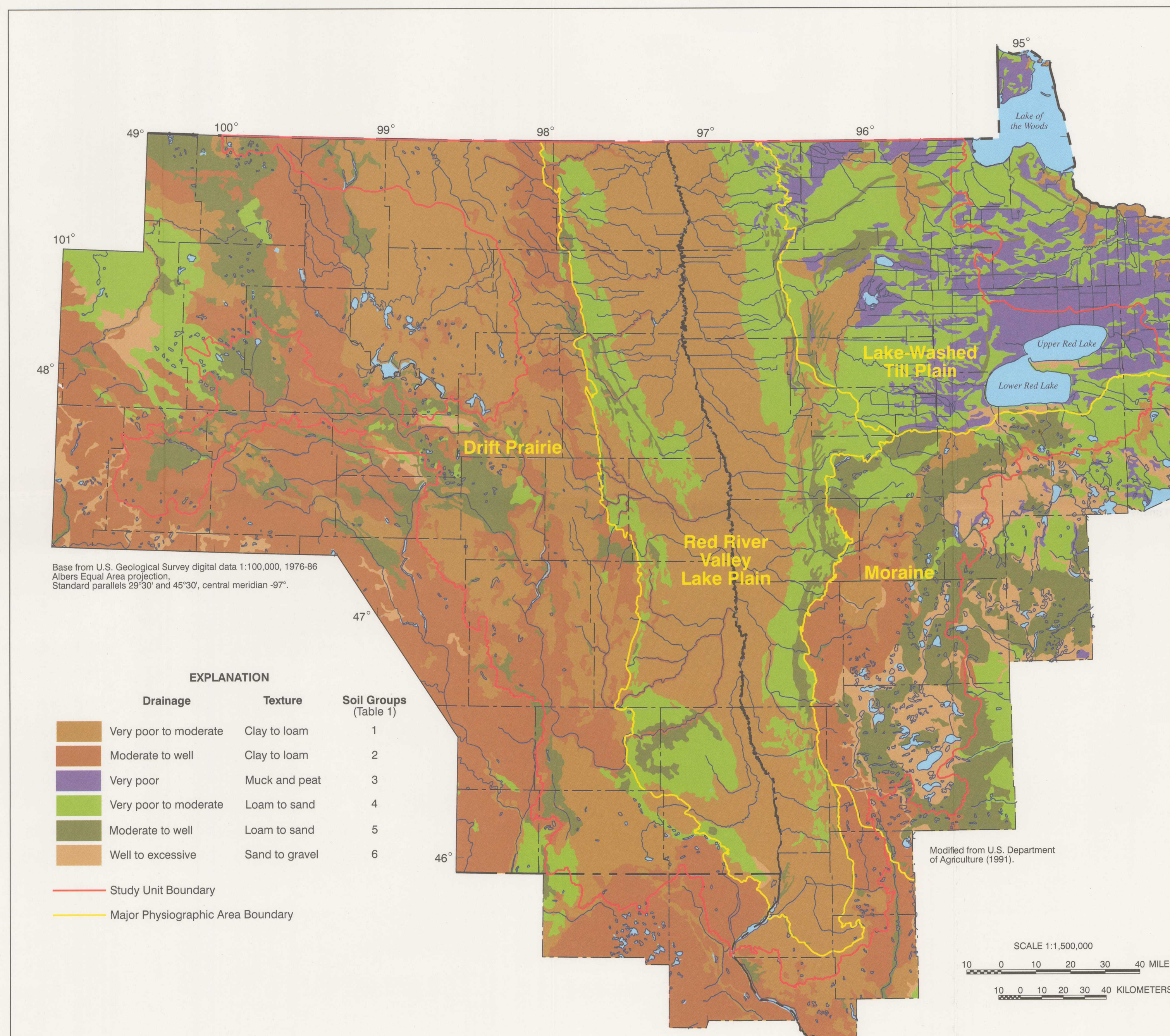


Figure 3. Soils associations groups, grouped by general drainage and texture characteristics, in the Red River of the North Basin study unit.

Soils

Soils differ from one another in the proportion of pore spaces, the size and type of mineral material, and the amount and source of organic material. Mineral material consists of sand-, silt-, and clay-sized particles. Clay-sized particles, which have a larger ratio of surface area to volume than the sand or silt particles, are the most active chemically with water and are essential for supporting the growth of plants.

The mineral material in soils of the Red River Basin study unit primarily is glacial sediments. Surficial deposits more recent than glacial origin are wind-blown sands in the southwestern part of the study unit, and river alluvium. Soils derived from the glacial deposits range from poorly drained clays and silts to well-drained sands on beach ridges and outwash plains. Organic soils and peat are common in depressional areas and in the Lake-Washed Till Plain.

A soil association is a mapping unit that contains a definite pattern of soils. The association is based on similarities in slope, texture, natural drainage, and special features. The soils that comprise the association are classified according to climate (soils that have a freeze-thaw cycle differ from those that do not), natural vegetation (soils in forested areas differ from those in grassland areas), topography (soils on steep slopes are generally thinner than those on plains), and other distinguishing features, such as the proportions of sand, silt, and clay. The soil association data used in this project are from the State Soil Geographic Data (U.S. Department of Agriculture, 1991). These data are available nationwide and were used for national consistency in soils data.

The soil drainage and texture information shown on figure 3 is based on measured characteristics for soil associations. The soil associations were grouped by similar drainage and texture of the dominant soils of the association. The soil groups shown on figure 3 must be interpreted within the context of the physiographic area. Specifically, the soils of the Drift Prairie are primarily northern prairie soils (borolls); the soils of the Red River Valley Lake Plain are primarily wet prairie soils (aquolls); the soils of the Moraine are northern forest soils (boralfs) and borolls; and the soils of the Lake-Washed Till Plain are wet, poorly developed soils (aquents), organic-rich soils (hemists), and aquolls.

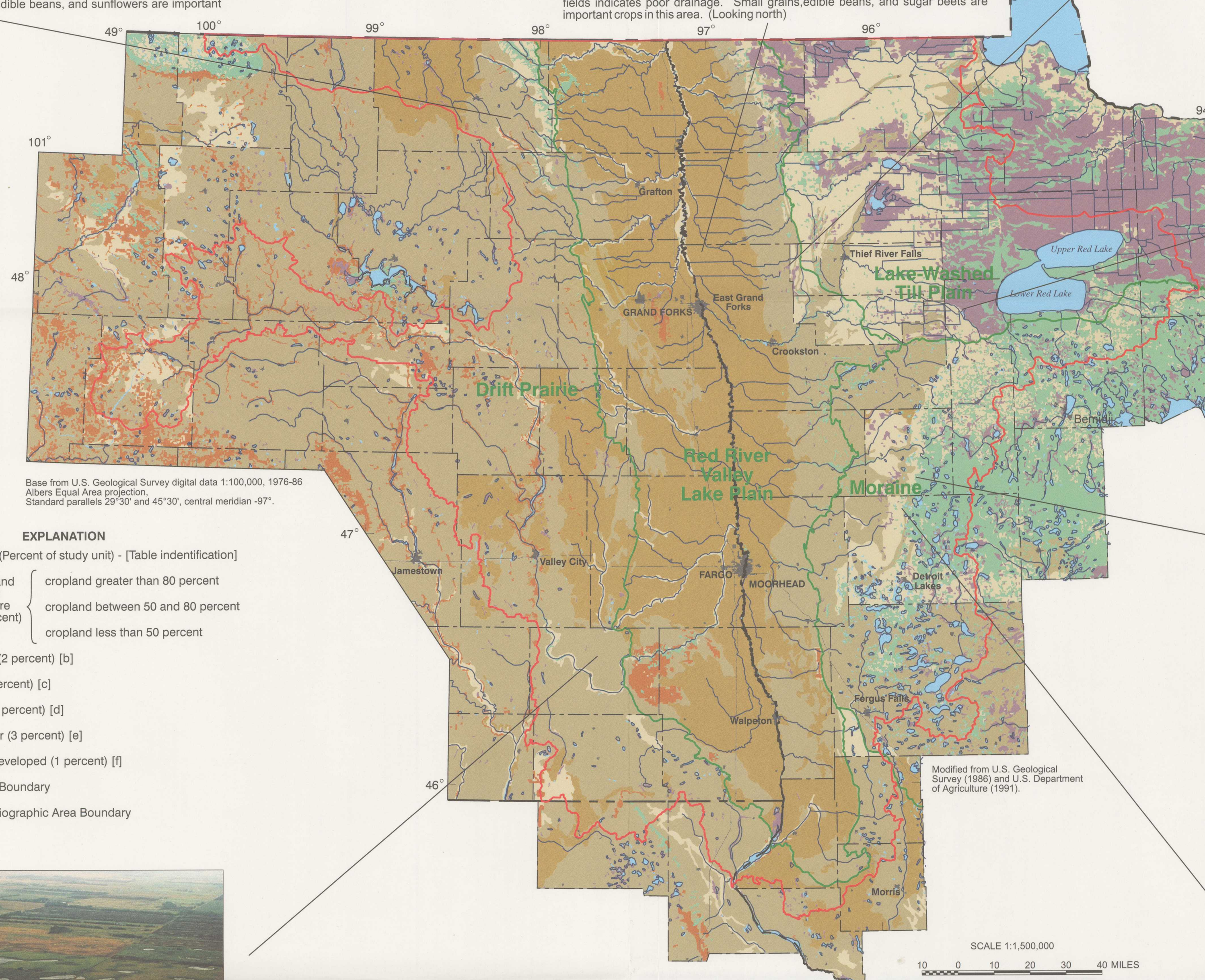
The nature of soil drainage can differ from one region to another for the same soil group. For example, the very poorly to moderately well drained, clay to loam textured soils (group 1) of the Red River Valley Lake Plain form extensive areas that are poorly drained. In contrast, group 1 soils in the Drift Prairie are characterized by many small poorly drained areas (prairie potholes). Therefore, emphasizing the consideration of physiographic area is critical to the context of the soil group.

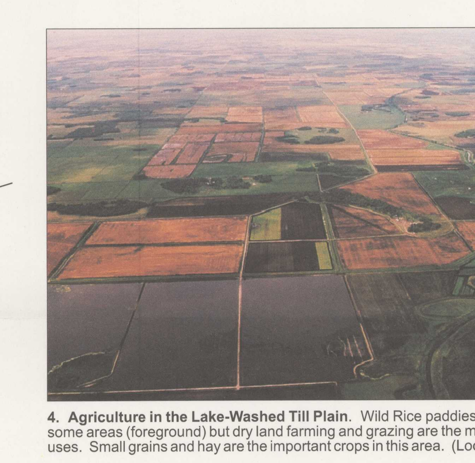
Soil affects the crops grown and the agricultural practices. Sugar beets are grown almost exclusively on the poorly drained loam (group 1) of the Red River Valley Lake Plain. Corn is grown on the poorly to moderately-well drained sand (group 4) of the Red River Valley Lake Plain, the excessively drained sandy soil (group 6) of the Moraine, and on the poorly to moderately well-drained sandy loam (group 2) in the southern part of the Red River Valley Lake Plain. Poorly drained soils are frequently ditched and typically plowed in the fall, so that they dry earlier the next spring. Excessively drained sandy soil requires irrigation; other excessively drained soils tend to be thin soils on steep slopes that are not cultivated.


1. Agriculture in the Drift Prairie. Fields commonly contain small wetlands areas called prairie potholes. Small grains, edible beans, and sunflowers are important crops in this area. (Looking west)


2. Agriculture in the Red River Valley Lake Plain. The pattern in the foreground fields indicates poor drainage. Small grains,edible beans, and sugar beets are important crops in this area. (Looking north)


3. Agriculture in the beach-ridge area of the Red River Valley Lake Plain. Note large areas of wetlands and former cropland in the upper right part of the image. Small grains, edible beans, and sunflowers are important crops in this area. (Looking northeast)




4. Agriculture in the Lake-Washed Till Plain. Wild Rice paddies are common in some areas (foreground) but dry land farming and grazing are the major agricultural uses. Small grains and hay are the important crops in this area. (Looking west)


5. Mixed agriculture-forest typical of the Northern Hardwood Forests area of the Moraine. Small grains, soybeans, and sunflowers are important crops in this area. (Looking north)


7. Agriculture in the Drift Prairie. Note the prairie potholes and windbreaks. Small grains, soybeans, and sunflower are important crops in this area. (Looking northwest)


6. The Lakes and Forest Ecoregion of the Moraine. (Looking east)

Figure 4. Land cover and land use in the Red River of the North Basin study unit.

Land Cover and Land Use

Cropland and pasture is the dominant land cover category throughout most of the Red River Basin study unit (fig. 4). The extent of cropland varies throughout the study unit. For example, in Traill County, North Dakota, agricultural statistics (North Dakota Agricultural Statistics Service, 1992) indicate cropland accounts for almost 90 percent of the area shown as cropland and pasture on figure 4; whereas, agricultural statistics (Minnesota Agricultural Statistics Service, 1993) indicate that only 60 percent of the cropland and pasture for Marshall County, Minnesota is cropland. The 10 percent remaining in Traill County can be accounted for by homesteads, local roads, and a small amount of pasture. The 40 percent remaining for Marshall County is primarily due to cropland that has been taken out of production (Dave Rose, U.S. Department of Agriculture, oral commun., 1992) and pasture.

The distribution of crops varies throughout the region, because of differences in soil and climate. Wheat and barley are the major crops, and are grown throughout the basin. Corn and soybeans primarily are grown in the southern parts of the Red River Valley Lake Plain and the Moraine and in the extreme southern part of the Drift Prairie. Edible beans are grown in the northern half of the Red River Valley Lake Plain. Sunflowers are common in most of the Drift Prairie, in the northwestern part of the Moraine, and along the border between the Red River Valley Lake Plain and the Lake-Washed Till Plain. Sugar beets are grown throughout the Red River Valley Lake Plain. Potatoes are grown on rich, well-drained soils found primarily in the northwestern part of the Red River Valley Lake Plain. Hay and pasture are found throughout the basin, but are most extensive in the Lake-Washed Till Plain, in the Moraine, and along river valleys in the Drift Prairie.

Other land covers include grassland, forest, wetland, open water, and urban or developed. Grassland areas are unsuitable for cropland and generally are used for grazing cattle. The major area of forest cover is in the central and eastern part of the Moraine. This forest is primarily covered by northern hardwoods and small areas of conifers. Logging is a minor activity in the forest. Many lakes of various sizes are found in the Moraine, and the Lake-Washed Till Plain contains four large lakes. The Lake-Washed Till Plain contains vast areas of wetland, both open and forested. This area was heavily ditched during the 1930's in an effort to claim additional land for cultivation, but is largely unused today. The Drift Prairie and the southern part of the Moraine contain numerous small prairie potholes. There are two major urban areas, Fargo-Moorhead and Grand Forks, where about 165,000 people lived in 1990. These three cities contain about 32 percent of the population of the Red River Basin study unit.

Sampling-Site Stratification and Design

The water-quality assessment for the Red River Basin study unit addresses large-scale questions, such as the presence, distribution, and loads of nutrients and pesticides associated with large agricultural regions across the Nation. This assessment also begins to address major local and regional concerns about water quality. In 1991, a liaison committee comprised of organizations and interested individuals helped identify water-quality issues summarized below in decreasing order of concern. These issues were used in conjunction with the environmental framework to develop the 1993-95 sampling of the Red River Basin study unit.

1. Toxic contamination from nonpoint sources--primarily from pesticides and fertilizer application for agriculture, but also certain trace metals such as mercury and lead, which may come from the air.

2. Salinity and radionuclides from naturally occurring sources--ground water from some deep bedrock aquifers is known to contain large concentrations of dissolved salts that can migrate upward into fresher sand and gravel aquifers and into streams. Naturally occurring radionuclides, such as radon and radium, also may have elevated concentrations in ground water.

3. Soil erosion and sedimentation--large areas of clayey to silty soil are eroded by wind and water and moved into streams and reservoirs. Specific effects of sediment on stream biota and the amount of nutrients and toxic substances carried by this sediment are not well understood.

4. Eutrophication--the enrichment of surface water with nitrogen and phosphorus causes algal blooms and other problems in surface-water.

5. Toxic contamination by point sources--although much progress has been made to mitigate these type of discharges over the past 20 years, water managers still are concerned about cumulative effects of point discharges of treated municipal and industrial (sugar beet, grain, and meat processing) effluent which are mainly discharged to the Red River and some of its major tributaries.

Primary components for stratifying the sampling design for streams and surficial aquifers are the four major physiographic areas (fig. 2 and table 1), which exhibit relatively homogeneous environmental factors. The physiographic areas are closely related to surficial geologic units. Each area exhibits fairly consistent soil type, land use and cover, and climatic and hydrologic conditions (Stoner and others, 1993).

Table 1.—Environmental framework for water-quality sampling.

Surface Components (streams and surficial aquifers)

Primary—physiographic area:
- A = Drift Prairie
- B = Red River Valley Lake Plain
- C = Lake-Washed Till Plain
- D = Moraine (in Minnesota)

Secondary—general drainage characteristics and dominant soil texture
1. Poorly drained clay, silt, or loam
2. Moderately well-drained clay, silt, or loam
3. Very poorly drained organic material
4. Poorly drained sandy loam or sand
5. Moderately well-drained sandy loam or sand
6. Excessively drained sand or sand and gravel

Tertiary—land cover and land use
- a. Cropland and pasture
  - Primary crops
    - * small grains (wheat, barley)
    - * corn and soybeans
  - Secondary crops
    - * sunflowers
    - * potatoes
    - * sugar beets
    - * dried beans
- b. Grassland
- c. Forest
- d. Wetland
- e. Open water or other unclassified
- f. Urban or developed

Subsurface Components (buried aquifers)

Bedrock area
- E = Saline discharge from bedrock aquifers
- F = Non-saline discharge from bedrock aquifers

A secondary framework component is soil drainage and texture. These characteristics of soil can affect both surface water and near-surface ground water. For example, aquifers underlying coarse soil (groups 4, 5, and 6) can be more readily affected by human activities than aquifers underlying fine textured soil. Furthermore, stream runoff and sediment load are affected by soil drainage and texture.

The third component is land cover and land use (table 1). Land cover can affect the hydrologic characteristics of a basin and can directly affect surface water quality such as the amount of suspended sediment and organic carbon. Land use can affect the amount of suspended sediment in surface water and nutrients and pesticides in streams and shallow ground water. Crops that are grown can affect the amounts and types of pesticides and fertilizer applied. Cropping patterns are used to estimate pesticide and fertilizer application rates. Cropping patterns are classified based on primary national (corn, soybeans, wheat and other grains, and alfalfa) and important specialized or secondary crops (Gilliom, R.J., and Thelin, G.P. U.S. Geological Survey, written commun., 1996). Wheat and other small grains are the primary crops in most areas in the Red River Basin study unit. Sunflowers, potatoes, sugar beets, and dry edible beans are specialized crops in some areas. Some areas in the southern part of the study unit have corn and soybeans or corn and small grains as the primary crops.

In general, applications of nitrogen and phosphorus vary across the Red River Basin study unit according to the framework described above. Tornes and Brigham (1994) summarized 1985 county statistics (Alexander and Smith, 1990) on nitrogen and phosphorus applications. Total phosphorus applications (from chemical fertilizers and from manure) are proportional to total nitrogen applications throughout the study unit. The smallest applications were reported for areas along the upland basin boundaries, such as Pierce and Sheridan Counties, N. Dak., Marshall County, S. Dak., and Beltrami and Clearwater Counties, Minn. The largest applications were reported for areas of extensive cropland within the Red River Valley Lake Plain, such as Norman, Stevens, Traverse, and Wilkin Counties, Minn. and Cass County, N. Dak. Total application on cropland ranged from 16 to 84 pounds per acre (lb/ac) for nitrogen and 4 to 20 lb/ac for phosphorus. These application rates could be larger on specific fields.

The Red River Basin study unit was subdivided into two subsurface components, bedrock areas E and F (table 1) for assessing water quality in buried aquifers in glacial sediments. Bedrock area E (fig. 5, sheet 2) generally is where buried sand and gravel aquifers receive considerable recharge from underlying or adjacent sedimentary bedrock aquifers that contain saline ground water (1,000 to 57,000 milligrams per liter dissolved solids) under high hydraulic head. Bedrock area F is the remaining part of the study unit in which buried sand and gravel aquifers are partly recharged by relatively small amounts of saline or nonsaline ground water from bedrock formations. Stoner and others (1993) summarized how sedimentary bedrock aquifers and confining units within the eastern flanks of the Williston structural basin gradually thin eastward beneath the Red River Basin study unit (fig. 5). The Red River Valley Lake Plain contains some of the lowest land-surface altitude above these bedrock aquifers and provides a potential regional discharge area for saline ground water. The saline bedrock area (E) is based on geologic maps of bedrock geology (Bluemle, 1982, Jirsa and others, 1994) and test-drilling data (Moore, 1979). These maps and data show where the lower Cretaceous rocks, Jurassic rocks and the Ordovician part of the Cambrian-Ordovician aquifer (Downey, 1986) underlie glacial sediments beneath the study unit. These rocks are shown separately because they can produce distinct geochemical compositions of water and the Cretaceous rocks lie unconformably over the Jurassic, Ordovician, and Precambrian rocks (Stoner and others, 1993 and Charron, 1969). The Lower Cretaceous aquifer becomes thin or is covered by younger Cretaceous shales beneath the southern part of the Red River Valley Lake Plain (Richland, Roberts, Traverse and Wilkin Counties). Moore (1979) reported that well-log data could be misinterpreted to indicate the presence of Cretaceous sandstone, which may in fact be weathered low permeability Precambrian rocks. For these reasons the subcrop of the Lower Cretaceous aquifer in the southern part of the Red River Basin study unit is not included in bedrock area E.

The actual area of saline ground-water influence on glacial-sediment aquifers probably is smaller than indicated by bedrock area E in figure 5. The western boundary of subregion E is the top of the Mowry Shale in the Lower Cretaceous rocks, which is a confining unit that overlies the Lower Cretaceous aquifer. The presence of a confining unit may shift the western boundary of the saline area slightly to the east. The undifferentiated Jurassic rocks generally are considered to be a regional confining unit (Downey, 1986). Locally, test-hole drilling (Moore, 1979) suggested that the sandstone part of these rocks, located near the Red River, could produce saline water to flowing wells. Dilution by fresher ground water in glacial aquifers may effectively limit the eastward migration of saline ground water in the Ordovician and Lower Cretaceous aquifers, particularly in Minnesota. Previous ground-water studies indicated that saline ground water was present in buried sand and gravel east of the Red River (Maclay and others, 1972 and Lindgren, 1996).

Previous water-quality studies suggested that the natural salinity from bedrock aquifers was affecting the quality of surface water and soils in part of bedrock area E. Specifically in eastern Walsh and Grand Forks Counties, N. Dak., saline soils and wetlands have been documented in county soil surveys (Doolittle and others, 1981, and Hetzler and others, 1972). Strobel and Gerla (1992) suggested that slow leakage of saline ground water from bedrock through glacial sediments was reaching surface waters. Strobel and Haffield (1995) also noted that flowing wells discharging saline ground water to land surface over the last few decades may have increased the salinity in soils and surface waters. These saline areas resulted in measurable increases in salinity in the lower reaches of the Forest, Park, and Turtle Rivers during low-flow conditions. Although these tributaries only accounted for about 1.2 percent of the streamflow in the Red River during the fall and winter of 1992-93, they contributed 17 percent (192 tons per day) of the dissolved-solids load to the Red River (Strobel and Haffield, 1995). Based on a regional reconnaissance of baseflow in 1991, Cowdery and Brigham (1992) suggested that direct leakage of saline ground water to the Red River is small relative to the dissolved-solids load contributed by tributary streams.

For the purposes of the sampling stratification described in this report, subcrops of the Upper Cretaceous bedrock aquifer have not been shown on figure 5. Stoner and others (1993) described the chemistry of water from this bedrock aquifer located beneath the extreme western part of the Red River Basin study unit (fig. 5). The influence of the Upper Cretaceous aquifer on the natural chemistry of aquifers in the overlying glacial sediments is expected to be fairly localized.

Sampling design for water-quality sites relies on coordinated sampling of varying intensity and scope at two general types of sites--indicator and integrator (table 2, sheet 2). Indicator sites are chosen to represent water-quality conditions in a relatively homogeneous drainage basin characterized by a single environmental factor. Integrator sites are chosen to represent water-quality conditions of streams and rivers in heterogenous basins that are affected by combinations of environmental factors. Indicator sites could be nested within integrator sites to understand the cumulative effects of several different factors.

For practical purposes, several other criteria were considered in the final selection of the water-quality sites for the Red River Basin study unit. Existing monitoring stations and candidate stream sites were inspected in the field. Reconnaissance data were collected to determine suitability of sites for sampling water throughout the year, sampling aquatic biota, measuring streamflow, and assessing potential stream-aquifer interaction. The sampling design considers the majority of stream flow through the Red River Basin study unit, existing stream-gaging stations, and surficial aquifers that had fairly well defined hydrogeology from previous studies. Previous studies and a large amount of data on nutrients, pesticides, and suspended sediment were reviewed (Tornes and Brigham, 1994) to help understand the primary physical, chemical, and biological factors that affect water quality in the study unit. These reviews could not be used to rigorously test the proposed sampling-design stratification because of limited distribution of data and inconsistencies among the various data. However, some general observations from these reviews support the stratification by physiographic areas.